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US/French Joint Research Program

Regarding the Behavior of Polymer Base Materials Subjected to Beta Radiation

Volume 1: Phase-1 Normalization Results

F. J. Wyant, W. H. Buckalew, J. Chenion, F. Carlin,
G. Gaussens, P. Le Tutour, M. Le Meur

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U.S./FRENCH JOINT RESEARCH PROGRAM

REGARDING THE BEHAVIOR OF POLYMER BASE MATERIALS SUBJECTED TO BETA RADIATION

Volume 1: Phase-1 Normalization Results

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RELATED PUBLICATIONS IN THIS SERIES

Previous Publications

- W. H. Buckalew and F. J. Wyant, "Some Effects of Electrons Slowing Down in Materials With Application to Safety-Related Equipment Qualification," NUREG/CR-2581, SAND82-0449, Sandia National Laboratories, Albuquerque, New Mexico, March 1982.

- C. Alba, F. Carlin, J. Chenion, and C. Gaussens, "Comparative Study of the Behavior of Polymers Subjected to the Action of ß and γ Radiation," ORIS/LABRA-036, Compagnie ORIS Industrie, Gif-sur-Yvette, France, June 1983.

- W. H. Buckalew, F. J. Wyant, and G. J. Lockwood, "Response of Rubber Insulation Materials to Monoenergetic Electron Irradiations," NUREG/CR-3532, SAND83-2098, Sandia National Laboratories, Albuquerque, New Mexico, November 1983.

- W. H. Buckalew, "First Results from Electron Photon Damage Equivalence Studies on a Generic Ethylene-Propylene Rubber," NUREG/CR-4543, SAND86-0462, Sandia National Laboratories, Albuquerque, New Mexico, April, 1986

Planned Future Publications

- "U.S./FRENCH JOINT RESEARCH PRO- GRAM REGARDING THE BEHAVIOR OF POLYMER BASE MATERIALS SUBJECTED TO BETA RADIATION Volume 2: Phase-2a Screening Test Results,"

- "U.S./FRENCH JOINT RESEARCH PROGRAM REGARDING THE BEHAVIOR OF POLYMER BASE MATERIALS SUBJECTED TO BETA RADIATION Volume 3: Phase-2b Expended Test Results,"

- "U.S./FRENCH JOINT RESEARCH PROGRAM REGARDING THE BEHAVIOR OF POLYMER BASE MATERIALS SUBJECTED TO BETA RADIATION Volume 4: Phase-3 Synergistic Effects Test Results,"

ABSTRACT

As part of the ongoing multi-year joint NRC/CEA international cooperative test program to investigate the dose-damage equivalence of gamma and beta radiation on polymer base materials, dosimetry and ethylene-propylene rubber (EPR) specimens were exchanged, irradiated, and evaluated for property changes at research facilities in the U.S. (Sandia National Laboratories) and France (Compagnie ORIS Industrie). The purpose of this Phase-1 test series was to normalize and cross-correlate the results obtained by one research center to the other, in terms of exposure (1.0 MeV accelerated electrons and Co^{60} gammas) and postirradiation testing (ultimate elongation and tensile strength, hardness, and density) techniques. The dosimetry and material specimen results indicate good agreement between the two countries regarding the exposure conditions and postirradiation evaluation techniques employed.

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EXECUTIVE SUMMARY

A multi-year joint NRC/CEA international cooperative test program to investigate the dose-damage equivalence of gamma and beta radiation on polymer base materials is currently under way. The results of this program should lead to a determination of the adequacy of gamma simulators, the equivalent level of gamma-to-beta ratio, and the appropriate simulation method to be employed in exposing equipment to radiation for qualification.

The joint research program is divided into three phases:

1. Normalization
2. Gamma damage equivalence of beta radiation
   a. Screening tests
   b. Expanded tests
3. Synergistic effects of mixed radiation fields.

The Phase-1 (Normalization) test series has been completed and is the subject of this report. The purpose of this test series was to cross-correlate and normalize the results obtained by one research group to the other (Sandia National Laboratories in Albuquerque, New Mexico, and the Laboratory of Biological Applications of Radiation at the Saclay Nuclear Research Center in Gif-sur-Yvette, France). The Phase-1 tests considered one material type (EPR--one U.S. formulation and one French formulation), one material thickness (1-mm), one electron energy (1.0 MeV), one gamma source (Cobalt-60), one exposure dose (150 kGy = 15 Mrad), and one dose rate (2.8 $Gy \cdot s^{-1}$ = 1 Mrad/h). The irradiated samples were then measured for changes in tensile strength, ultimate elongation, hardness, and density, using standard testing techniques.

In addition, dosimetry samples were exchanged and exposed in each electron and gamma facility. The conditions of exposure were the same for each dosimeter (1.0 MeV electrons or Co^{60} gammas, 2.8 $Gy \cdot s^{-1}$ and 20 kGy total dose). After exposure, the dosimeters were returned to the country from which they originally came and evaluated.

The Phase-1 dosimetry results indicate excellent correlation between the two countries regarding radiation exposure conditions and dosimetry measurement techniques. The Phase-1 EPR test results indicate that consistency is achievable between the two countries for the conditions of material exposure and postirradiation testing techniques employed.

After a preliminary study of the Phase-1 results, it was agreed to continue with the program's Phase-2 Screening Test effort.

1. INTRODUCTION

This document details the Phase-1 test series employed during the joint Franco-American research program regarding the behavior of polymer base materials subjected to beta radiation. The Phase-1 test series was designed and conducted to determine if the irradiation techniques and postexposure test facilities and techniques employed by each country are sufficiently similar so that the results to be obtained during the later phases of the joint research program can be correlated.

The purpose of the overall research program is to determine the photon dose required to impart damage equivalent to that resulting from electron energy deposition in selected organic materials. This equivalence can then be used to establish the adequacy of isotopic gamma sources in simulating the effects of loss of coolant accident (LOCA) beta radiation.

Experiments are to be conducted over a range of dose rates in order to determine which photon dose and dose rate most closely correlates with the damage occurring from electron radiation. For these experiments an accelerated electron beam will be used to simulate the LOCA beta radiation energy deposition profiles and resultant damage in the materials, whereas the photon energy deposition profiles are obtained by using a Cobalt-60 source.

Following irradiation, measurements are performed on each sample. These measurements include tensile tests, density determinations, and hardness determinations. The same tests are also performed on unirradiated, baseline, samples for comparison.

The joint research program is separated into three phases:

Phase-1: Normalization

Phase-2: Gamma damage equivalence of beta radiation
- a. Screening tests
- b. Expanded tests

Phase-3: Synergistic effects of mixed radiation fields.

The research program is being conducted jointly by research teams at the Saclay Nuclear Research Center and Sandia National Laboratories under an agreement between CEA and U.S. NRC. The results of the Phase-1 test series are discussed in detail within the following sections.

2. BACKGROUND

The purpose of these experiments is to determine the equivalence

of LOCA beta and gamma environments so that the suitability of Cobalt-60 gamma irradiations used to simulate the LOCA irradiation environments (during equipment qualification tests, for instance) may be evaluated. LOCA radiation environments are complex in that in addition to time dependent dose rates, the beta and gamma energy spectra are also time dependent. Simulation of these spectra, or their macroscopic effects, is yet to be demonstrated. Equivalence of electron-photon irradiations, on a microscopic level, is an accepted fact and is the basis for many dosimetry methods in use today (e.g., Bragg-Gray cavity ionization detectors).

Even though the LOCA gamma spectra are time dependent, their simulation with (relatively) high energy photon sources is generally valid. Insulation materials are usually relatively thin, such that even low energy (~0.1 MeV) photon beams penetrate these materials and only a few percent (<10%) of the photons undergo collisions in the material. Since the beam losses are minimal, this implies a uniform irradiation/energy deposition is assured with photon irradiations of almost all energies. On the other hand, low energy electrons traversing the same material will transfer a large fraction of their incident energy in the target material. Large energy transfer implies rapid beam depletion and nonuniform energy deposition. As electron beam energy increases, energy loss decreases and energy deposition becomes more uniform with penetration.

When studying electron-photon equivalence, the energy of the incident photon beam is relatively unimportant for thin sample irradiations; electron energy is, however, always an important parameter.

Based on the complex nature of the LOCA radiation spectra, faithful reproduction of these spectra, for relative effectiveness studies, is not practical. Rather a more reasonable approach is to study the relative effects of several monoenergetic electron irradiations, on materials, with respect to the effects from a single energy photon source.[1]

Accordingly, initial discussions of a joint research effort were held between representatives of the U. S. Nuclear Regulatory Commission (NRC), the Commissariat a l'Energie Atomique (CEA), Sandia National Laboratories (SNL), and the Saclay Nuclear Research Center--Laboratory of Biological Applications of Radiation (LABRA) in May 1984. A draft test procedure was issued in August 1984 and revised during a programmatic review meeting held in October 1984. The revised test procedure was issued as a final document[2] in November 1984, and the agreement between NRC and CEA[3] was later formalized in December 1984. Work began on the Phase-1 test series in January 1985 and was completed in September of that year. Work on the Phase-2 Screening Tests was begun in October 1985.

3. PHASE-1 TEST PROCEDURES

The Phase-1 (Normalization) tests were performed at both SNL and LABRA. This test series considered one material and one material thickness, one electron energy, and one exposure dose. The purpose of the Phase-1 test series was to cross-correlate and normalize the results obtained by one facility to the other. This normalization process addressed the differences of dosimetry (cellulose triacetate and polychlorostyrene), electron accelerators (VULCAIN and PELLETRON), gamma irradiation facilities (POSEIDON and Sandia's NGIF), and postirradiation testing techniques.

In order to provide the data required for normalization, specimens of the same organic materials (one French and one U.S. formulation) were irradiated under the same conditions of electron energy (1.0 MeV) or gamma source (Cobalt-60), dose rate (2.8 $Gy \cdot s^{-1}$), and exposure dose (150 kGy). The irradiated specimens were then measured for changes in tensile strength, ultimate elongation, and hardness, using standard testing techniques. In addition, small samples (approximately three cut from each half-sheet) were tested for relative--to virgin samples--changes in material density. Changes in electrical properties (e.g., dielectric breakdown) were not measured during the Phase-1 normalization test series.

Dosimetry samples were exchanged (SNL supplied the polychlorostyrene and LABRA supplied the cellulose triacetate) and irradiated on each electron accelerator and in each gamma irradiation facility. The conditions of exposure were the same for each dosimeter specimen (i.e., 1.0 MeV electrons or Co^{60} gammas, 2.8 $Gy \cdot s^{-1}$, and 20 kGy total dose). Sandia also exposed dosimeters to 0.5 MeV electrons at the PELLETRON facility. Sandia was responsible for postexposure dose determinations of all polychlorostyrene material, and LABRA responsible for the postexposure dose determinations of the cellulose triacetate material.

The following subsections detail the normalization parameters and irradiation conditions employed during the Phase-1 test series.

4. DOSIMETRY

The dosimeters used by LABRA for comparing γ- and β-ray measurement are cellulose triacetate (TAC) films, 8 mm wide and 0.125 mm thick. French dosimetry is based on the change in transmissivity of the exposed cellulose triacetate film. Transmissivity determinations are performed using a spectrophotometer.

In addition to using this industrial-type dosimeter, LABRA also used the services of the Ionizing Radiation Metrology Laboratory

(LMRI), which placed, either simultaneously during γ ray measurement or subsequent to and under the same conditions as ß ray measurements, calibrated Alanine dosimeters. The LMRI is certified in France by the National Bureau of Metrology. Its cooperation during the comparison tests run on U.S. and French dosimeters has provided LABRA with an independent check of its measurement device calibration.

LABRA supplied a total of seven cellulose triacetate dosimeters that were irradiated in the following manner:

2-unexposed blanks (1 for LABRA, 1 for SNL)
1-exposed to 1.0 MeV electron radiation at LABRA
1-exposed to 1.0 MeV electron radiation at SNL
1-exposed to 0.5 MeV electron radiation at SNL
1-exposed to gamma radiation at LABRA, and
1-exposed to gamma radiation at SNL.

The three samples sent to Sandia for irradiation along with the unexposed blank were returned to LABRA for measurement. Each sample was returned with a description of conditions of exposure (e.g., dates and time of exposure, total calculated dose, calculated dose rate, beam energy if applicable, and a notice of any anomalies occurring during exposure).

SNL dosimetry is based on the difference in transmissivity of exposed thin film dosimeters (dye-loaded polychlorostyrene, described in Reference 4) when compared to unexposed blanks. Transmissivity determinations are performed at Sandia on a scanning microdensitometer.

The polychlorostyrene (PCS) dosimeters used by SNL during the Phase-1 test series were 150 mm x 150 mm ($\pm$2 mm) sheets, 0.05 mm thick.

SNL supplied seven polychlorostyrene dosimeters that were irradiated in the following manner:

2-unexposed blanks (1 for LABRA, 1 for SNL),
1-exposed to 1.0 MeV electron radiation at LABRA
1-exposed to 1.0 MeV electron radiation at SNL
1-exposed to 0.5 MeV electron radiation at SNL
1-exposed to gamma radiation at LABRA, and
1-exposed to gamma radiation at SNL.

The two samples sent to LABRA for irradiation along with the unexposed blank were returned to Sandia for measurement. Each sample was returned with a description of conditions of exposure (e.g., dates and time of exposure, total calculated dose, calculated dose rate, beam energy if applicable, and a notice of any anomalies occurring during exposure). Sandia then performed

the dosimetry evaluations in accordance with the method outlined in Reference 5.

4.1 γ-Ray Exposures

French and American dosimeters were exposed to Cobalt-60 in the POSEIDON irradiator at Saclay and in the North Gamma Irradiation Facility (NGIF) at Sandia.

4.1.1 Irradiation Conditions

The irradiation conditions were as follows:

Dose absorbed in the air at dosimeter location = 20,000 Gy (2 Mrad).
Dose rate = 2.8 $Gy \cdot s^{-1}$ (1 Mrad/h).

Figure 1 is a schematic representation of the POSEIDON irradiation facility. It consists of two Cobalt-60 source planes spaced 512 mm from each other. Each source plane, items 1 and 2 (Figure 1), contains three source levels: A (bottom), B (middle), and C (top).

The radiocobalt section with the highest activity was placed at levels A and B. Figure 2 shows the location and the activity of each of the radioactive cobalt sources on January 1, 1985. The most active sources are placed on the edge of each source support, the least active in the center. This provides a wide photon field.

The activity of the sources of each one of the supports A1, A2, B1, and B2 is around 1550 TBq (42,000 curies). That of sources on the top support, C1, is 622 TBq (16,800 curies) and that of top support C2 is 666 TBq (18,000 curies). The total radioactivity of the 6 source supports in the POSEIDON irradiator was around 7400 TBq (200,000 curies) on January 1, 1985.

The dosimeters exposed in France were first placed on a 450 x 302 x 10 mm polymethyl methacrylate plate. The dosimeters were then located between the two planes of the POSEIDON radiocobalt sources.

The dosimeter support plate was placed 100 mm from the source 1 plane. Its center was at the level of the intersection of the bottom level (A) and the middle level (B) of the Cobalt-60 sources (Fig.1). The source planes are significantly larger than the plate supporting the dosimeters to ensure that the photon flux is fairly constant over the entire surface of the support.

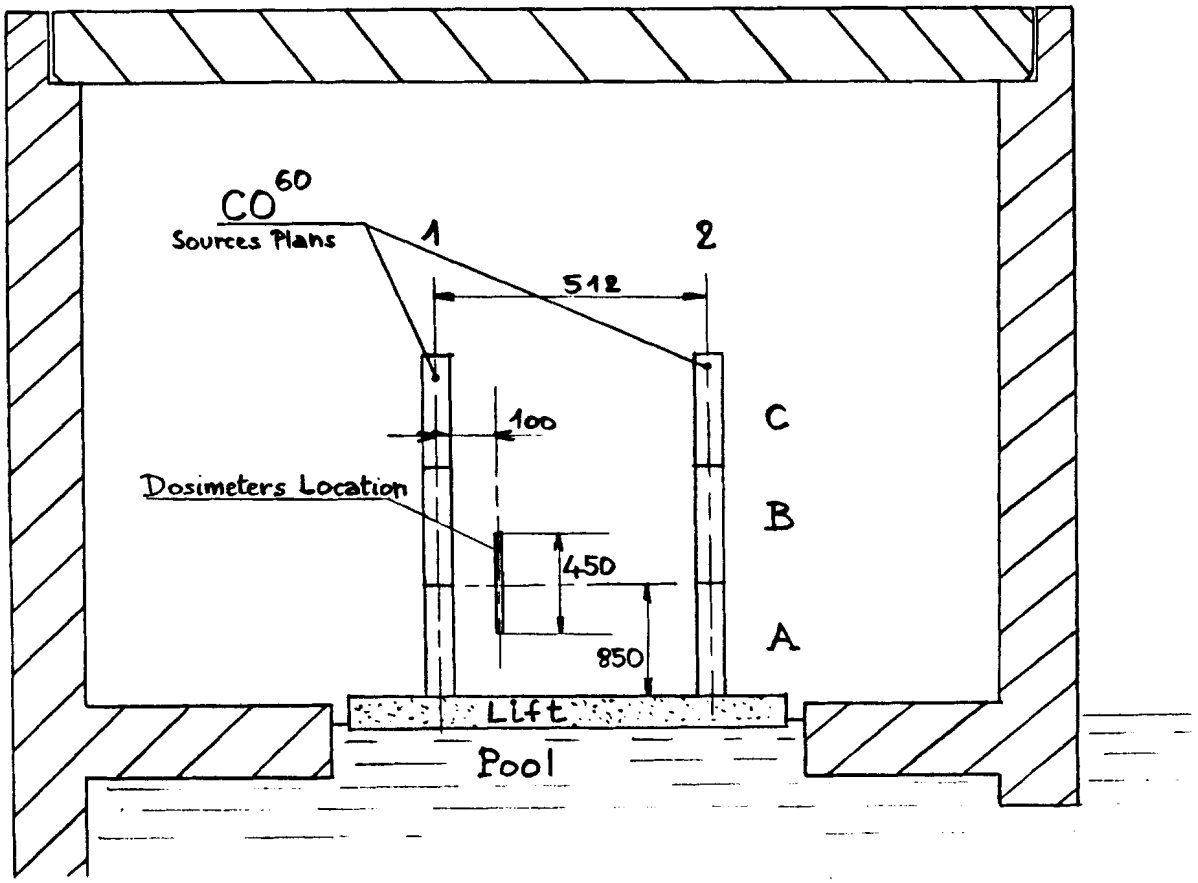

Figure 1: Target Location in the POSEIDON Gamma Irradiator.
(Dimesions are in millimeters.)

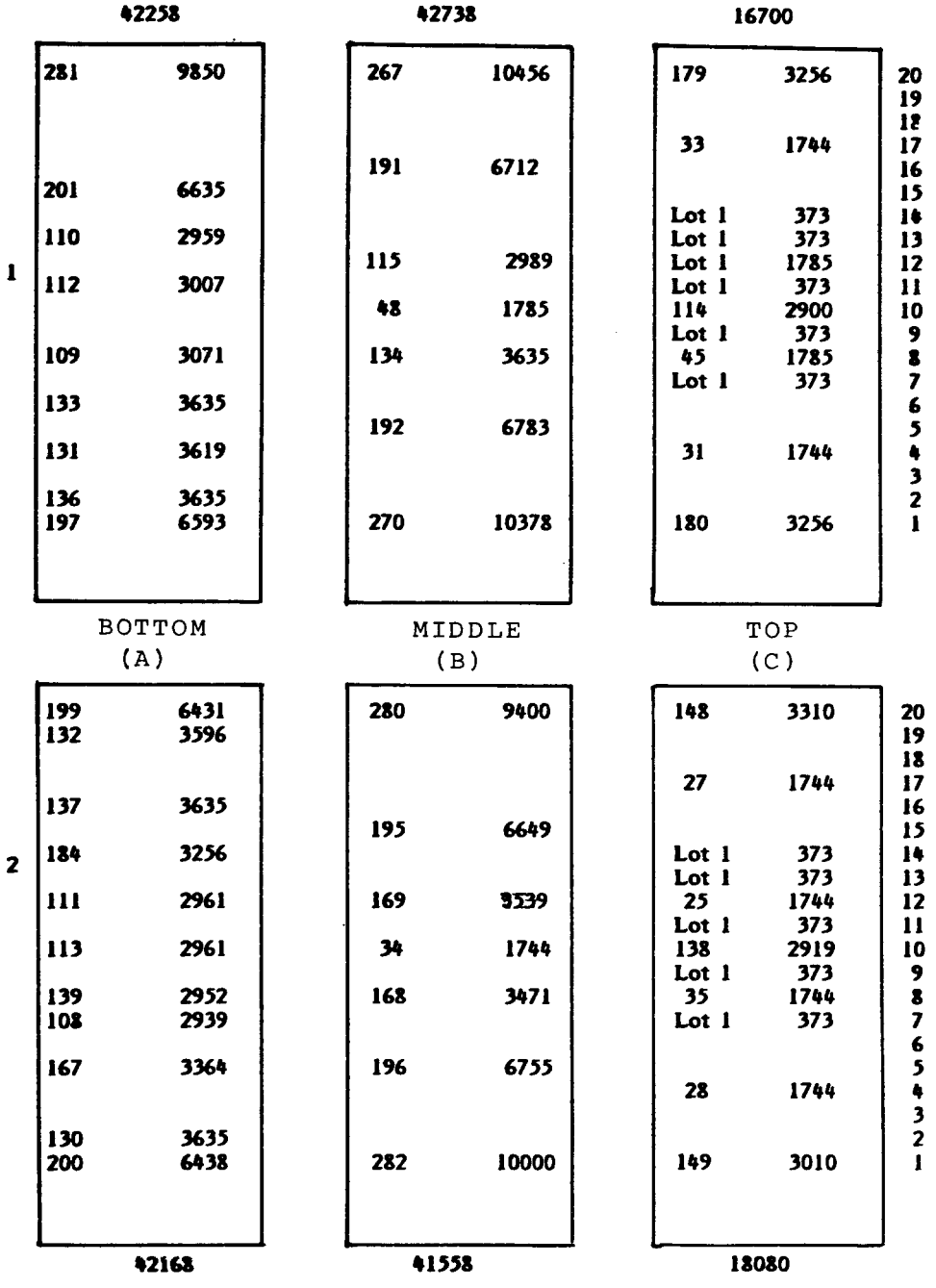

Figure 2: POSEIDON Co^{60} Sources Location and Their Activity (in curies) on January 1, 1985.

Figure 3 shows the location of the dosimeters on the polymethylmethacrylate support. Three types of dosimeters were irradiated simultaneously:

- The American PCS dosimeter was placed in the center of the support.

- An Alanine calibration dosimeter was placed at the middle of each of the American dosimeter edges. The four calibration dosimeters are marked as items 1, 2, 3, and 4 in Figure 3.

- The strips of the six French film dosimeters of TAC were placed on the edge of the polymethylmethacrylate support.

The NGIF is a rectangular Cobalt-60 source which is made up of 65 pencils, in a 450 mm wide x 300 mm high x 250 mm deep array.[6] The two major source planes are the left and right sides of the array. The source is enclosed in a large, air filled, shielded cubical structure; air in the cubicle is maintained at near ambient temperature and pressure conditions.

During exposure, the target dosimeters were placed 120 mm from the right source plane (outside of the array), at a level where the midplane of the target was at the midplane of the source. Figure 4 shows the relationship between the target and the NGIF sources. Thus the effective exposure source plane was 450 mm wide by 300 mm high during the Phase-1 irradiations.

The total activity of the NGIF Cobalt-60 source was around 1850 TBq (50,000 curies) on January 1, 1985.

The TAC dosimeter exposed in the U.S. to the NGIF Cobalt-60 source was equilibrated (placed between two 3-mm thick 150 x 150 mm plates of polymethyl methacrylate). The PCS dosimeter exposed to the NGIF source was also equilibrated.

4.1.2 French Dosimeter Readings

The Alanine calibration dosimeters were put in place and measured by LMRI.

The French industrial TAC dosimeters were measured using a spectrophotometer. The film optical density measurement is recorded by a plotter as the film passes in front of a monochromatic light beam whose wavelength is 280 nanometers (Figure 5).

A nonexposed strip and an opaque strip from the same reel used for testing are also measured. These two strips are

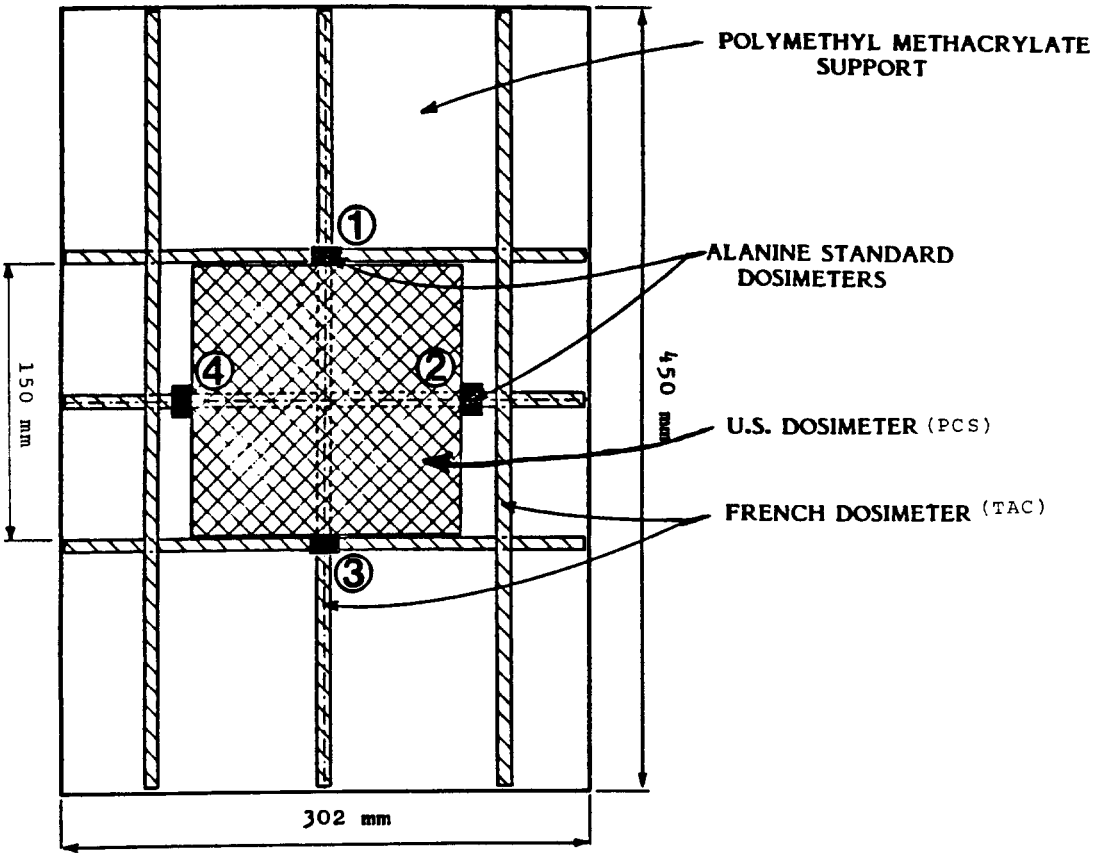

Figure 3: Dosimeters Location on the Support During γ Irradiation in POSEIDON.

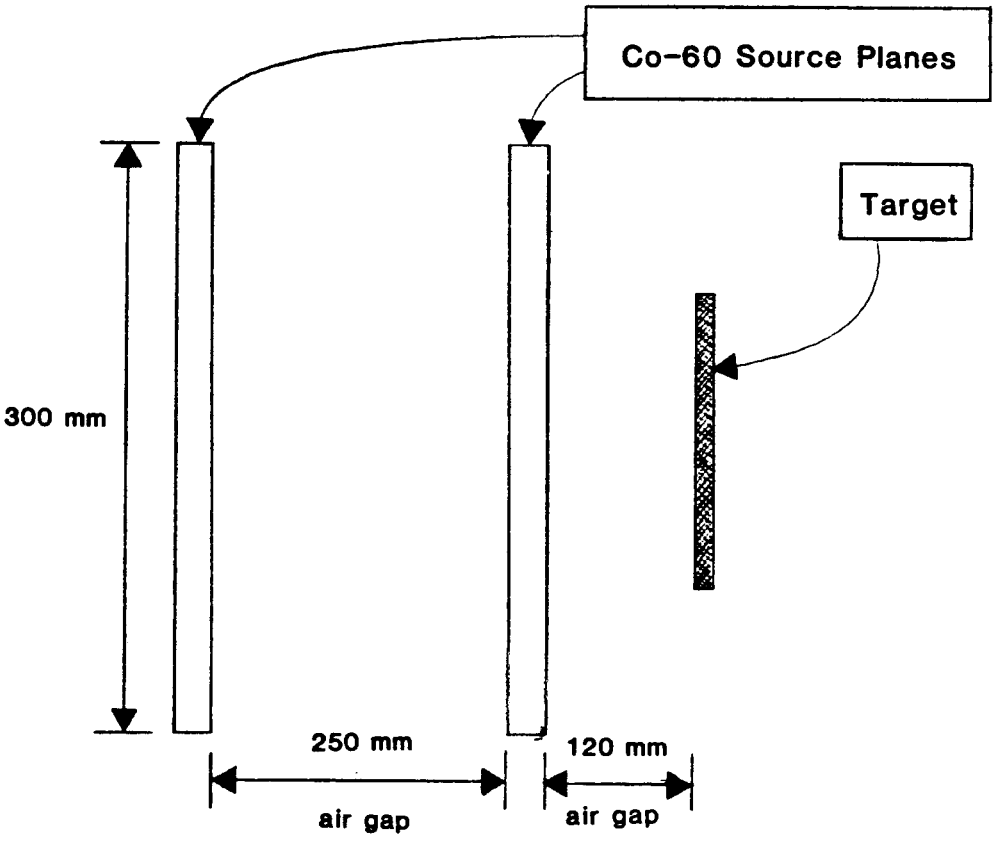

Figure 4: Schematic of the NGIF Co^{60} Source, Air Gap, and Target.

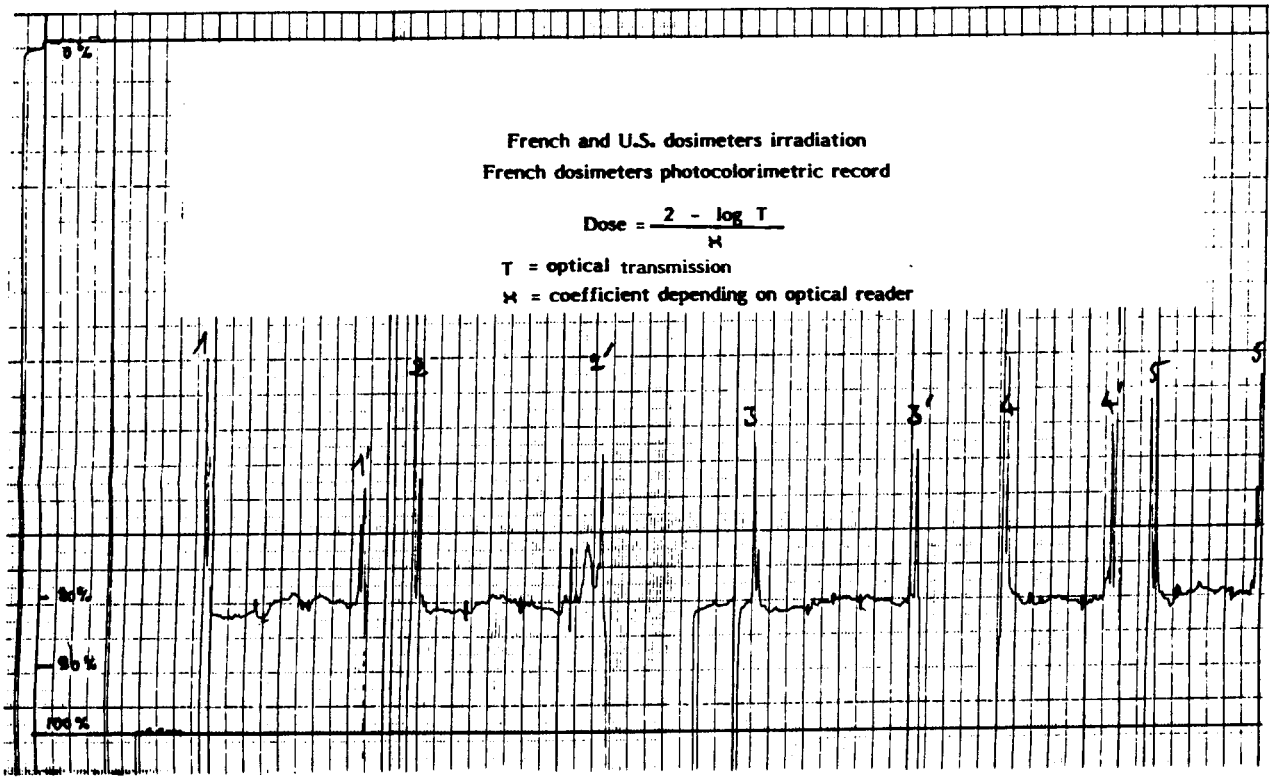

Figure 5: Example of the French Spectrophotometer Measurement as Recorded by a Plotter.

used as references; the former represents an optical transmission of 100% and the latter 0%.

The measurement of the dose of radiation absorbed is defined by:

$$D = \frac{2 - \log T}{\aleph}$$

where T is the optical transmission, in percent, of the irradiated TAC film and $\aleph$ is a constant that depends on the various parameters of the measurement system.

The measurement of the dose of radiation absorbed in the air at the location of the TAC film is known with an uncertainty of $\pm$15%.

4.1.3 U.S. Dosimeter Readings - Methods and Accuracy

The PCS dosimeters were calibrated on January 2, 1985, in the NGIF and compared to readings obtained with an NBS traceable air ionization probe. The range of doses obtained during the dosimeter calibration run was 5-25 kGy.

The calibrated PCS dosimeters were then read using a scanning microdensitometer, at a 430 nanometer monochromatic light beam wavelength. The results of these calibration runs determined the coefficients (A and B) of the equation:

$$D = A\ (OD)^B$$

where D is the dose (to air), and OD is the optical density of the irradiated PCS film, as provided (directly) by the microdensitometer.

The Phase-1 PCS dosimeter measurements were made by scanning each 150 mm by 150 mm sheet four times: twice using a 1.72 neutral density wedge (top-to-bottom and left-to-right), and twice using a 0.85 neutral density wedge. A dose, corresponding to the average optical density obtained, was calculated for each scan using the above equation (where the values of A and B are unique to the neutral density wedge being used). The average of the four scan doses thus derived is the value listed for each PCS dosimeter discussed in the following subsections.

The measurement of the dose to air at the location of the PCS is known with an uncertainty of $\pm$10%.

4.1.4 Results of Measurements Made in POSEIDON

Figure 6 shows the results of the measurement of the dose absorbed in the air over 127 minutes at different characteristic points on the plate supporting the set of French and American dosimeters, especially,

- at the center of the American dosimeter (PCS)
- in the middle of each edge of the American dosimeter
- at the intersection of each French film (TAC) with the edge of the polymethyl methacrylate support plate.

The following statements can be made:

a. Minimum absorbed dose is equal to 18.9 kGy
b. Maximum dose is equal to 21.3 kGy.

The difference in the dose absorbed over the entire surface of the plate is hence equal to 2.4 kGy.

Figure 3 shows the location of the Alanine calibration dosimeters, points 1, 2, 3, and 4.

Table 1 gives the measurements made in the POSEIDON irradiator. It shows:

a. An excellent correlation between the measurements made with the American dosimeter (PCS) and the Alanine calibration dosimeters.

b. A very acceptable correlation between the French dosimeters (TAC) and the American dosimeters (PCS). The uncertainty in the measurements made with the two dosimeters, PCS and TAC, largely overlaps. The two measurements are different by 12% maximum and the measurement uncertainties equal to 10% and 15% respectively.

Hence, for the dosimeters irradiated in the POSEIDON facility,

Measurement made with TAC = 20.8 $\pm$ 3.2 kGy
Measurement made with PCS = 22.8 $\pm$ 2.3 kGy

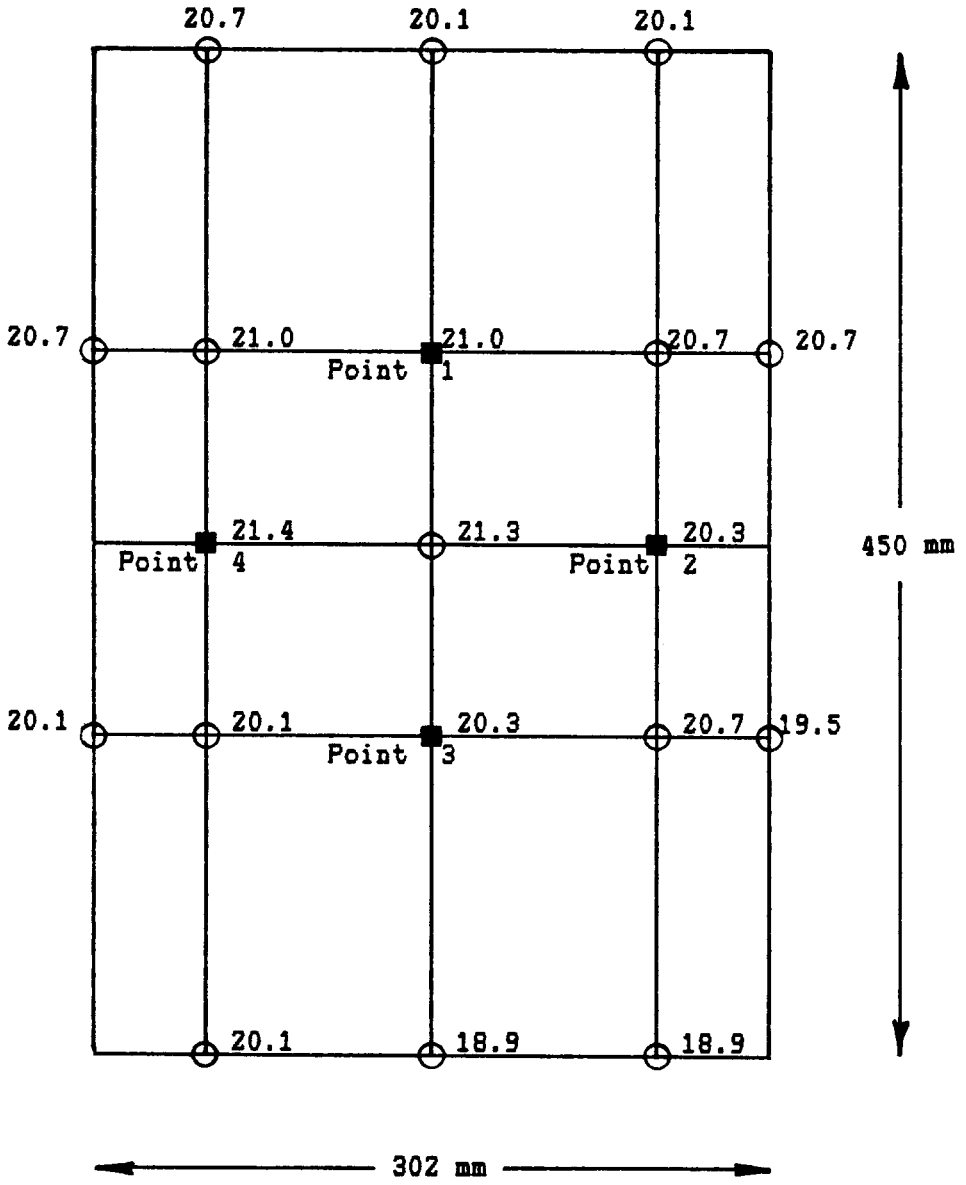

Figure 6: Doses Absorbed In Air On The Dosimeter Support In kGy, during Irradiation at the POSEIDON facility.

TABLE 1

Comparison of the Measured Doses between French TAC, Alanine, and U.S. PCS. Irradiation time was 127 minutes, in the POSEIDON Facility. Alanine measurements were carried out by French N.B.S. (Location numbers refer to those shown in Figure 3 for the Alanine and in Figure 6 for the TAC.)

LOCATION	ALANINE (kGy)	TAC (kGy)	PCS (kGy)
1	22.9 ± 1.3	21.0 ± 3.2	22.8 ± 2.3
2	22.2 ± 1.3	20.3 ± 3.2	
3	22.2 ± 1.3	20.3 ± 3.2	
4	22.6 ± 1.3	21.4 ± 3.2	

In conclusion, the two methods for measuring the dose absorbed in the air at the location of the dosimeters give thoroughly comparable results. The differences observed on the measurement of the radiation dose are sufficiently slight so as to be insignificant as to the effects they may have on the properties of the irradiated polymers.

4.1.5 Results of Measurements Made in the NGIF

The measurements of the dose absorbed in air at the loca- tion of the French dosimeters (TAC) and the American dosim- eters (PCS) irradiated in the NGIF at SNL are very close to each other. The difference is equal to 3%, while the uncertainty for the two measurements is greater than 10%.

Hence, for the dosimeters irradiated in the NGIF,

Measurement made with TAC = 22.2 ± 3.3 kGy

Measurement made with PCS = 21.4 ± 2.1 kGy

4.2 Electron Exposures

The second part of the program comparing the means used for

radiation dosimetry involves the measurement of radiation from accelerated electrons.

The VULCAIN electron accelerator is a Van de Graaff, hence a dc type device, whose energy can be varied from 0.5 to 3 MeV. Beam intensity can be continuously adjusted from a few microamps to 1 milliamp.

After being accelerated, the beam of electrons is deflected in one direction by an alternating field with a frequency equal to 200 hertz, and air scatter diffuses the beam in the other (perpendicular) direction. The length of the deflection is 40 centimeters at the electron outlet window.

The window is titanium foil 40 micrometers thick.

The PELLETRON is an electron accelerator with a variable steady-state (dc) beam energy and current capability (from 0.1 to 1.0 MeV, and from 0.001 to 34 μA). The electron beam is deflected in two orthogonal directions (vertical and horizontal) so that large surface areas may be irradiated uniformly.[7]

After being accelerated, the electron beam is deflected in an alternating field where the vertical control frequency is 100 hertz and the horizontal control is set at 33 hertz. The rastered beam then passes through a 50 micrometer thick beryllium window, into air, and toward the target.

The irradiation conditions of the dosimeters in France with the VULCAIN electron accelerator, as in America using a PELLETRON accelerator, are the following:

- The energy at accelerator outlet is 1 MeV.
- The intensity is adjusted so that the dose rate in the air at the location of the dosimeters is as near as possible to 2.8 Grays per second.
- The absorbed dose under these conditions, to dosimeters exposed over a two hour period, is close to 20 kGy.

4.2.1 French Electron Exposure Conditions

Prior to exposing the French and American dosimeters to the VULCAIN electron beam, preliminary tests were made to determine the dose gradient over the length of the beam path and to determine the locations of isodose at the target surface:

a. Dose gradient measurement over the length of beam deflection

A strip of TAC (cellulose triacetate) film was placed on a polystyrene support parallel to the length of the accelerator window.

Figure 7 shows the results of the dose rate as a function of scanning length for the 1 MeV electron beam. The dose rate is normalized to 1 at one end of the strip.

When the relative dose rate is 1 at 18 centimeters from the middle of the window, it is then equal to 1.25 at 11 cm., 1.2 in plumb with the middle of the window, decreases to 1 at 12 cm from the middle of the window, and drops to 0.8 at 18 cm from the other side of the middle of the window.

There are two possible explanations for this asymmetric dose rate gradient over the length of the electron beam deflection:

1. A current distortion at the input to the scanning coils, which induces a non-linear scanning field about the axis of the titanium window; or

2. A bad alignment of the scanner with respect to the accelerator tube axis.

The difference between the minimum and maximum dose rates is equal to 0.45 with a gradient equal to 0.025 relative units per centimeter between 4 and 12 cm from the center of the window.

b. Determination of the isodose lines on the dosimeter support surface

To define the location of the dosimeters used for comparing dose measurement methods, isodose curves were plotted on the surface of the polystyrene support.

Five strips of TAC film were placed parallel to the length of the support. The mid-length of the support coincided with the window mid-length.

Figure 8 shows the resulting plot of the isodose lines normalized to 1. The figure shows that it is necessary to place the dosimeters over the length of the support between 10 mm to the right of the middle of the plate and 140 mm to the left to obtain a maximum variation of

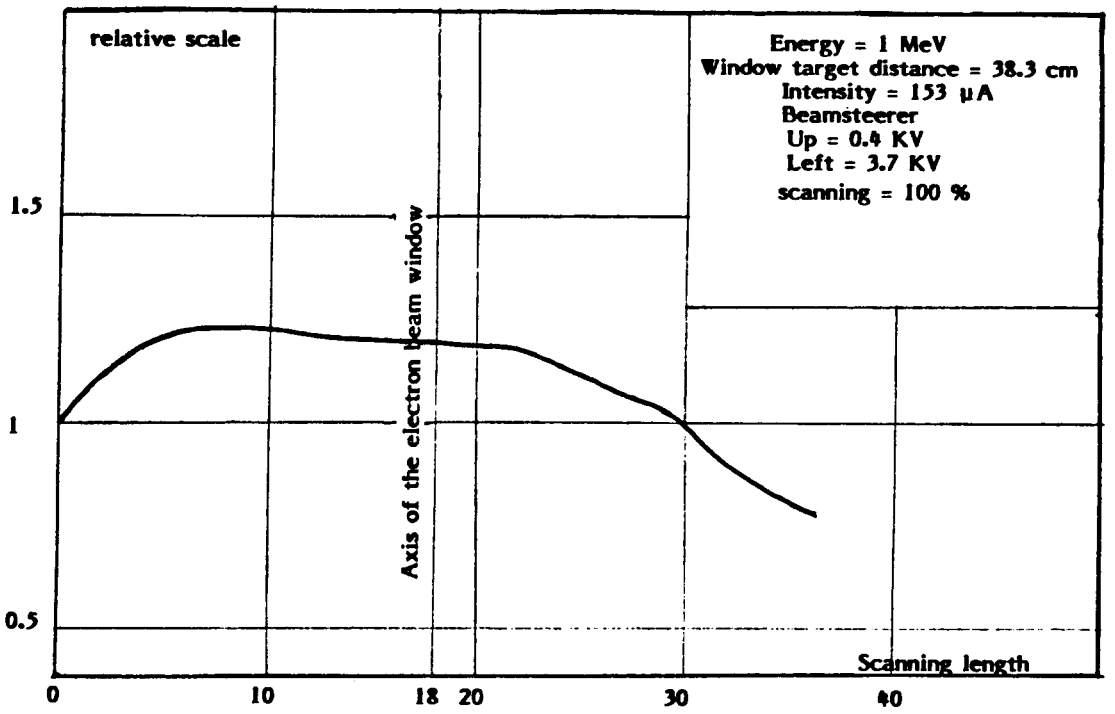

Figure 7: Dose-Rate Change Versus Scanning Length of the VULCAIN Electron Beam.

±10% of the dose rate over the surface of the 150 x 150 mm American dosimeter.

After the preliminary tests, beam intensity was set at 153 µA.

The French TAC (cellulose triacetate), and the American polychlorostyrene (PCS) dosimeters, and the Analine calibration dosimeters were placed in succession on a polystyrene plate 450 mm long and 302 mm wide. The dosimeter support plate was placed 38.3 cm from the electron outlet window.

The comparison of French and American dosimeters was made in two phases:

First the TAC (cellulose triacetate) dosimeter measurements were compared with the calibrated Alanine dosimeters.

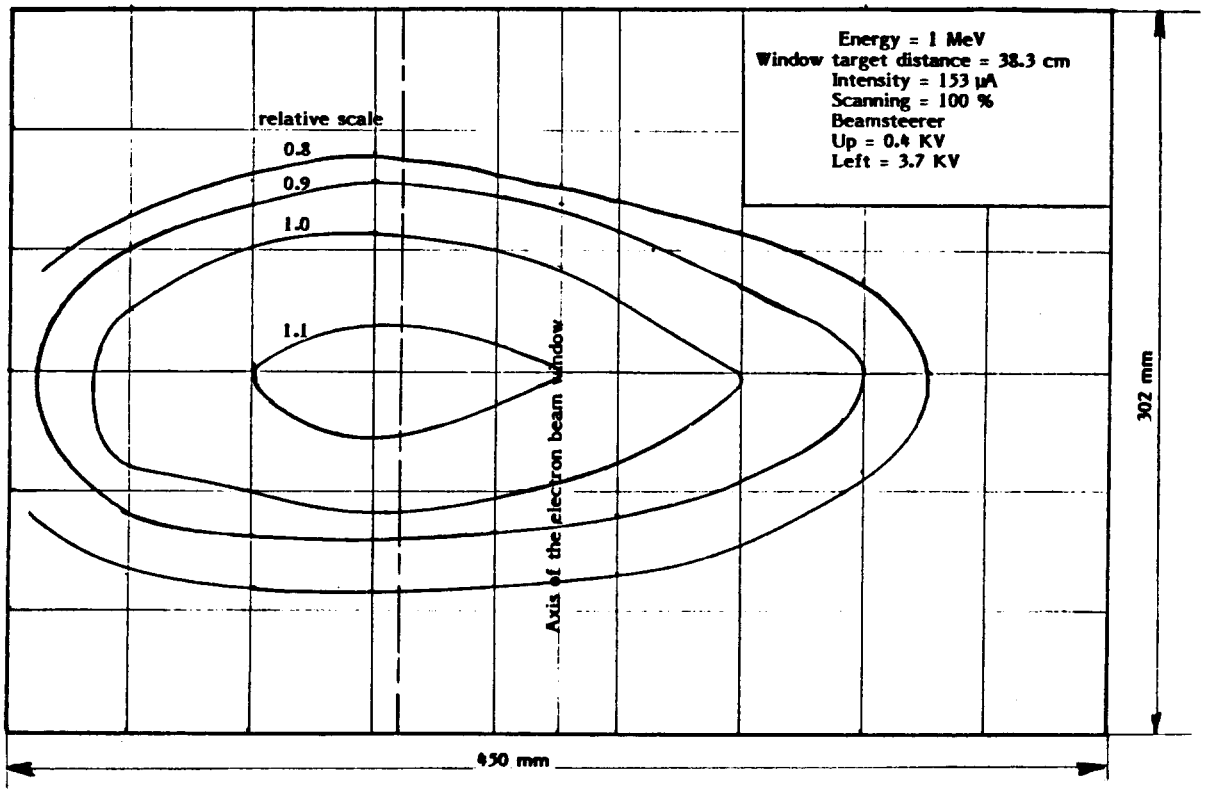

Figure 8: VULCAIN Electron Beam Isodose Lines At The Surface of the Dosimeter Support (Target).

Secondly, the American (PCS) and French (TAC) dosimeter measurements were compared.

Each type of dosimeter was irradiated singly, at the surface of the polystyrene support placed in exactly the same location and at the same distance from the VULCAIN accelerator window. None of the electron accelerator operating conditions were modified between irradiations.

Figure 9 shows the location of the three types of dosimeters (TAC, PCS and Alanine) on the polystyrene support.

The center of the PCS sheet coincides with the support mid-width and is placed 65 mm from the mid-length of the support plate.

Five Alanine dosimeters are placed respectively for four of the five (items 1, 3, 4, 5) at the middle of the edges of the American dosimeters, the fifth (item 2) at the center of the dosimeter.

Five TAC dosimeters were placed as follows:

- 1 TAC dosimeter is placed in the axis of the support. Hence, it coincides with the center of the PCS dosimeter and calibrated dosimeters 1, 2, and 3.

- 2 TAC dosimeters are placed on each side of and 70 mm from the support axis. Hence, they coincide with the two sides of the PCS dosimeter and calibration Alanine dosimeters 4 and 5.

- 2 TAC dosimeters are placed on each side of and 30 mm from the support axis. Hence, they coincide only with the PCS dosimeter.

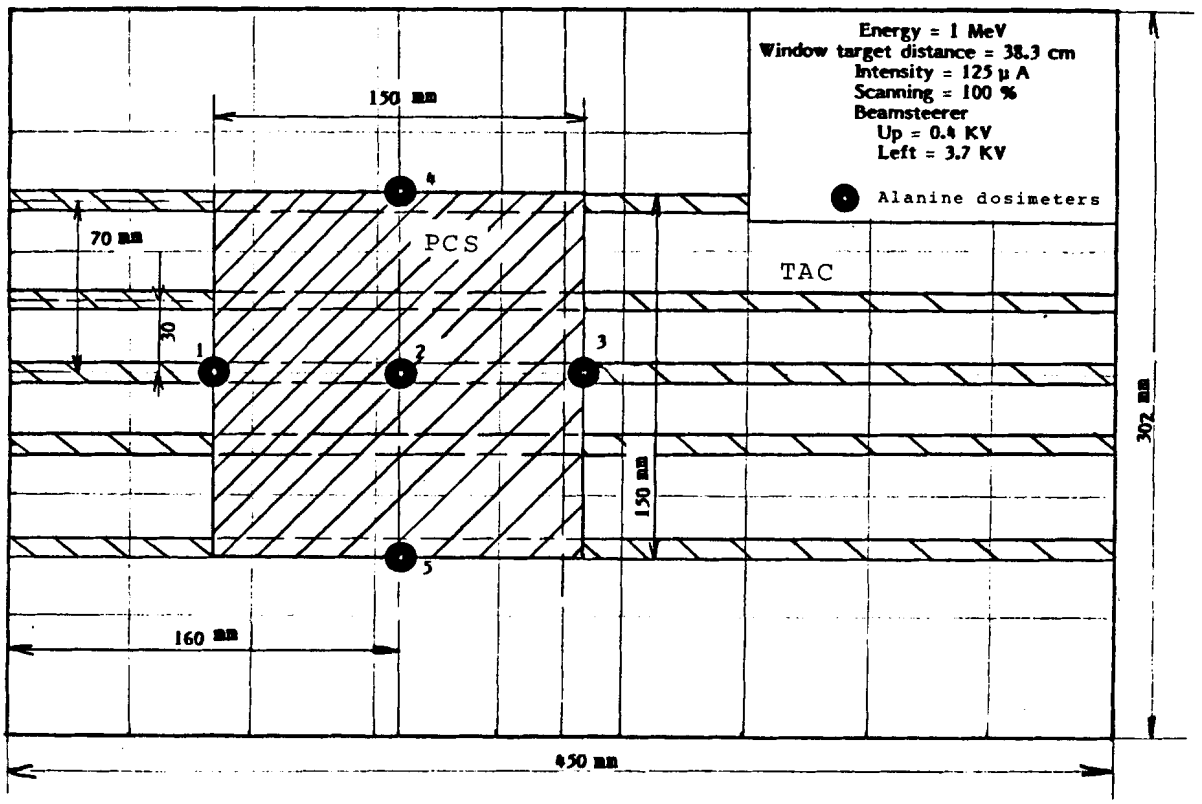

Figure 9: French and U.S. Dosimeters Location During Electron Irradiation at the VULCAIN Facility.

4.2.2 U.S. Electron Exposure Conditions

Prior to exposing the U.S. and French dosimeters to the electron radiation, several preliminary PELLETRON runs were conducted. The purpose of these tests was twofold:

1. to determine the raster coil drive currents and window-to-target distance necessary to uniformly irradiate 150 x 150 mm targets, and

2. to determine the electron beam currents required to provide a 2.8 $Gy \cdot s^{-1}$ dose rate at the target surface for both 1.0 and 0.5 MeV electron energies.

The results of these tests indicated that a combination of 700 mA coil currents, a window-to-target distance of 640 mm, and a total beam current of 1.9 µA gave a uniform 2.8 $Gy \cdot s^{-1}$ exposure over the target surface area at a beam energy of 1.0 MeV. For 0.5 MeV electrons the corresponding values were 440 mA coil currents, 480 mm window-target separation, and a beam current of 1.2 µA. (See Figure 10.)

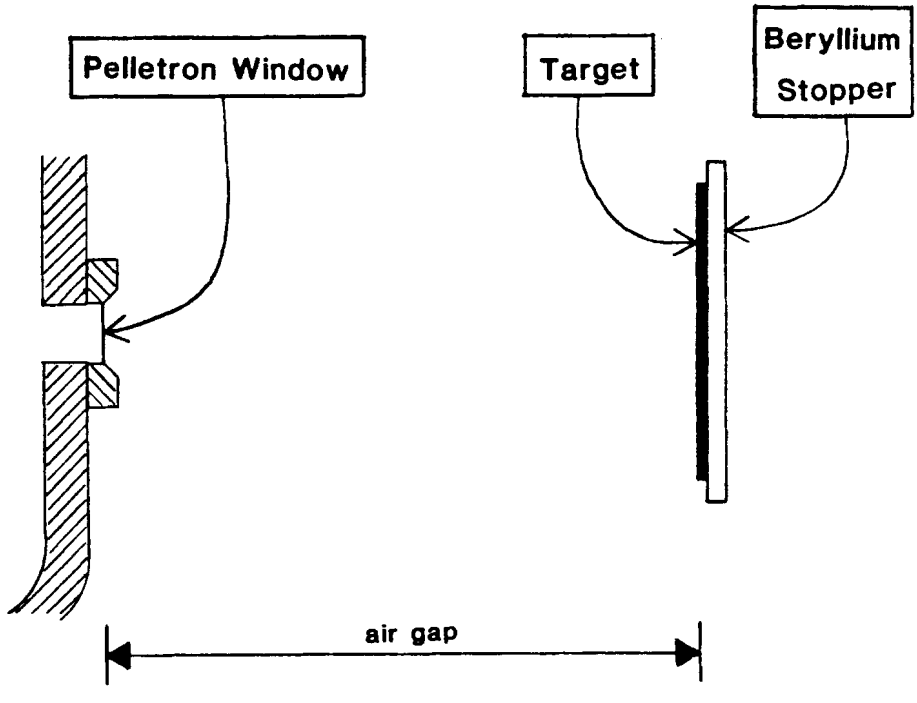

Figure 10: Schematic of PELLETRON Window, Air Gap, Target, and Beryllium Stopper.

Since the U.S. electron exposures of the dosimetry were to be carried out at 0.5 and 1.0 MeV particle energies, the PELLETRON parameters were set as discussed above, for each case.

A sample of U.S. PCS material was mounted on a 180 x 180 mm x 6 mm thick beryllium plate at the required window-to-target distance and then exposed to a total electron dose of 20 kGy. Following that, six 150 mm long strips of TAC material were mounted on the beryllium plate as shown in Figure 11 and then irradiated.

4.2.3 Results of Dose Measurements Made With TAC and Alanine

Table 2 shows the results of the TAC measurements of the absorbed dose rate in air and compares them to the Alanine dosimeter results at the same locations.

The measurements made using Alanine or TAC are virtually identical. They differ only by a maximum of 1.8%.

The maximum positional difference in measured TAC dose, equal to 18%, is between location 2 and 5, i.e., between the center position and one of the sides.

TABLE 2

Comparison of the average exposure dose rates between French TAC and Alanine, during a 2-hour exposure at the VULCAIN Facility. Accuracy obtained with Alanine is $\pm$ 14% at 1 MeV, by the French N.B.S.

DOSIMETER LOCATION	ALANINE DOSE-RATE $Gy \bullet s^{-1}$	TAC DOSE-RATE $Gy \bullet s^{-1}$	TAC DOSE KGy
1	3.55 $\pm$ 0.5	3.61 $\pm$ 0.56	26.1 $\pm$ 3.9
2	3.61 $\pm$ 0.5	3.61 $\pm$ 0.56	26.1 $\pm$ 3.9
3	3.3 $\pm$ 0.47	3.36 $\pm$ 0.5	24.3 $\pm$ 3.3
4	3.08 $\pm$ 0.44	3.06 $\pm$ 0.47	22.0 $\pm$ 3.3
5	3.0 $\pm$ 0.42	2.97 $\pm$ 0.44	21.4 $\pm$ 3.2

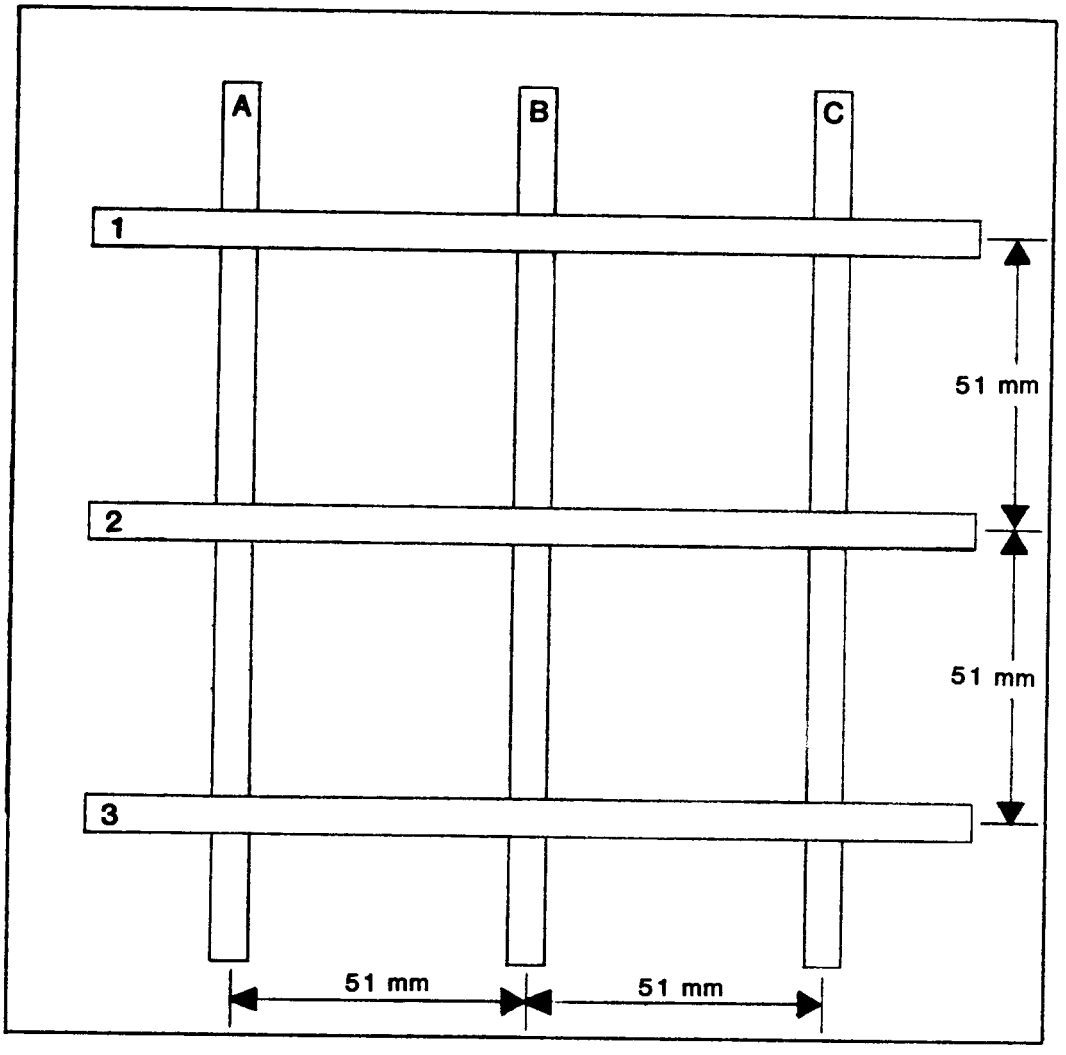

Figure 11: Arrangement of TAC Strips During Electron Irradiation at the PELLETRON Facility.

The variations between the center TAC position and the outer four positions are:

between locations 2 and 1 = 0% variation
between locations 2 and 3 = 7% variation
between locations 2 and 4 = 16% variation
between locations 2 and 5 = 18% variation

In conclusion, the correlation between the measurements made with the TAC dosimeter and the Alanine dosimeter is excellent.

4.2.4 Results of Measurement of Doses Made With TAC and PCS Using the French VULCAIN Accelerator

Figure 12 shows the location of the measurement of the dose absorbed in the air by the TAC dosimeters over a 120-minute irradiation period at VULCAIN. The locations are marked A to O inclusive for 15 measurements. The variation is a maximum of 13% between location H and location C.

The mean value of measurements A through O is equal to 18.9 kGy. The accuracy of the mean is calculated as the standard deviation with respect to the mean;

$$S = \left[\frac{\sum_{i=1}^{n} (D - \bar{D})^2}{n - 1} \right]^{1/2}$$

and gives,

$$S = \pm 0.8 \text{ kGy}.$$

Since the uncertainty associated with TAC dose measurements is 15% (as stated in Section 4.1.2), the total uncertainty of this measurement thus becomes $\pm$ 2.8 kGy. The reading of the PCS measurement was equal to 17.6 $\pm$ 1.8 kGy, hence:

Measurement made with TAC = 18.9 $\pm$ 2.8 kGy
Measurement made with PCS = 17.6 $\pm$ 1.8 kGy

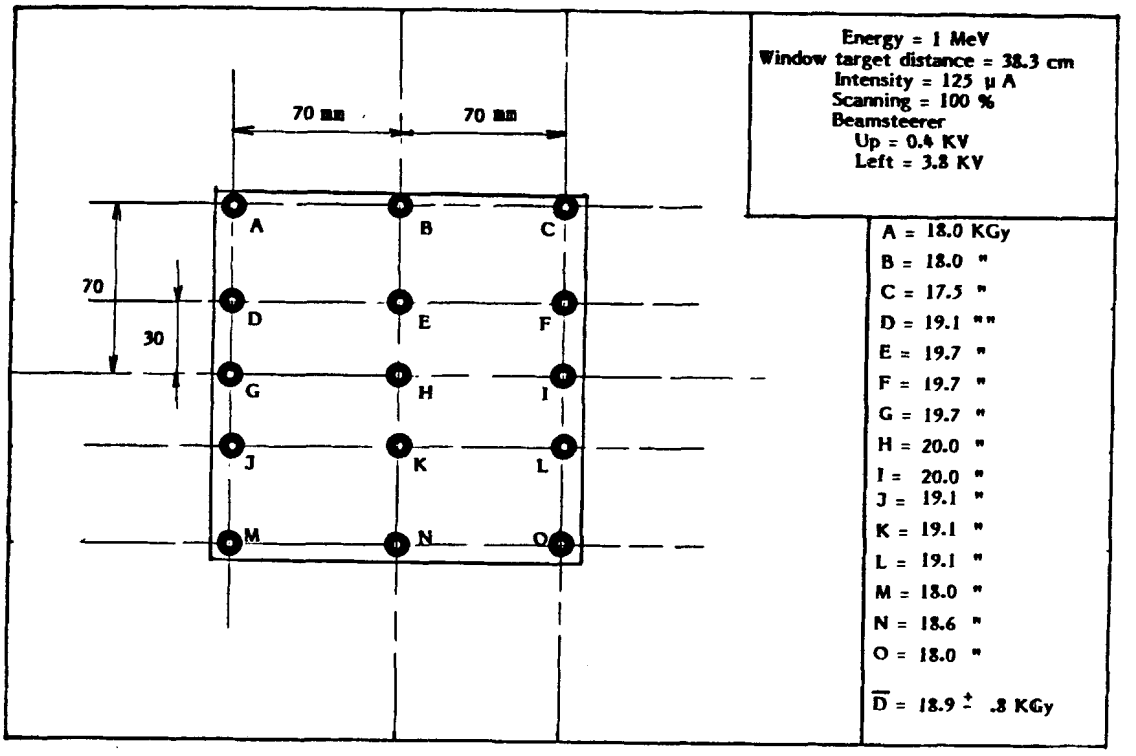

Figure 12: U.S. and French Dosimeters Irradiated in the Same Conditions at the VULCAIN Facility. French Dosimeter (TAC) Results are Tabulated.

The two measurements differ by 1.3 kGy, which is less than the PCS dosimeter uncertainty and less than the uncertainty of the TAC dosimeter.

In conclusion, the correlation between the measurements of the dose absorbed in the air at the location of the French dosimeters (TAC) and the American dosimeters (PCS) irradiated on the VULCAIN accelerator is very satisfactory for running the corresponding tests in the Franco-American Cooperation Program.

4.2.5 Results of the Measurements Made Using the American PELLETRON Electron Accelerator at 1 MeV

Figure 11 shows the location of the French dosimeters (TAC) on their beryllium support during irradiation by the

PELLETRON accelerator electron beam. Three dosimeters were positioned vertically (items A, B, and C). Three dosimeters were laid horizontally (items 1, 2, and 3), over the vertical strips.

The measurements of the doses absorbed using the TAC dosimeters are shown in Table 3; they were made at the intersection of the dosimeters. The location written 1A designates the measurement of the horizontal dosimeter (1) at the intersection of dosimeter 1 and dosimeter A; similarly, the location written A1 designates the measurement of the vertical dosimeter (A) at the intersection of dosimeters A and 1. The other location codes also follow this pattern.

The maximum dose obtained using French dosimeters (TAC) is 23.7 kGy at location B2 in the center of the support. The measurement of location 2B is also the highest of the measurements made on the horizontal dosimeters, 22.7 kGy.

The measurement of the minimum absorbed dose is obtained at locations 1C and C1 at one of the corners of the support, 18.6 and 18.0 kGy respectively.

Dose measurements differ by 18% from the center of the support and one of its corners (C1).

The mean of the horizontal dosimeter measurements is equal to 20.8 kGy, that of the vertical dosimeters is 21.4 kGy.

The mean of the set of French dosimeters (TAC) is equal to 21.1 kGy; that of the American dosimeter (PCS) measurements is equal to 20.6 kGy. The means differ by only 2%, hence:

Measurement made with TAC = 21.1 $\pm$ 3.2 kGy
Measurement made with PCS = 20.6 $\pm$ 2.3 kGy

The measurements differ by 0.5 kGy, which is much less than the uncertainties given for the PCS and TAC dosimeter measurements.

In conclusion, the correlation of the 1.0 MeV electron dose measurements is excellent for the dosimeters irradiated on the PELLETRON accelerator.

TABLE 3

Comparison of irradiation dose measurements made with French TAC and U.S. PCS, after a 120-minute exposure to 1.0 MeV electrons at the PELLETRON Facility.

LOCATION (Above)	DOSE KGy	LOCATION (Below)	DOSE KGy
1 A	19.0	A 1	18.8
1 B	20.3	A 2	23.2
1 C	18.6	A 3	21.9
2 A	21.4	B 1	23.0
2 B	22.7	B 2	23.7
2 C	21.4	B 3	22.6
3 A	22.5	C 1	18.0
3 B	20.8	C 2	21.5
3 C	20.8	C 3	19.7

MEASUREMENTS AVERAGE OF UPPER T A C = 20.8 KGy

LOWER T A C = 21.4 KGy

4.2.7 Results of Measurements Made Using the American PELLETRON Electron Accelerator at 0.5 MeV

Table 4 provides the results of the 0.5 MeV PELLETRON exposure dose measurements for the TAC and PCS dosimeters.

The maximum dose obtained from the French dosimeters (TAC) is equal to 19.7 kGy at location 2B in the center of the support. The minimum dose is obtained at corners 1C, C1 and C3 of the support.

The mean of the measurements made using the French dosimeters (TAC) is equal to 17.0 kGy. The American dosimeter (PCS) measurement gave 17.5 kGy, hence:

TABLE 4

Comparison of irradiation dose measurements made with French TAC and U. S. PCS, after a 120-minute exposure to 0.5 MeV electrons at the PELLETRON Facility.

LOCATION (Above)	DOSE KGy	LOCATION (Below)	DOSE KGy
1 A	15.9	A 1	17.3
1 B	17.3	A 2	18.5
1 C	15.9	A 3	16.8
2 A	18.0	B 1	15.9
2 B	19.7	B 2	16.7
2 C	17.5	B 3	15.5
3 A	17.3	C 1	15.9
3 B	18.0	C 2	16.4
3 C	17.3	C 3	15.4

MEASUREMENTS AVERAGE OF UPPER T A C = 17.4 KGy

LOWER T A C = 16.5 KGy

Measurement made with TAC = 17.0 ± 2.6 kGy
Measurement made with PCS = 17.5 ± 2.3 kGy

Again the measurements differ by 0.5 kGy, which is much less than the uncertainties given for PCS and TAC measurement techniques.

The correlation between the 0.5 MeV electron dose measurements is excellent for the dosimeters irradiated on the PELLETRON accelerator.

4.3 Summary of Phase-1 Dosimetry

Figure 13 compares the dosimetry results of both countries, where the solid line represents the target dose of 20 kGy. The points are plotted in pairs, representing similar exposure locations (U.S. or France) and radiation particle type (gamma or electron). The circles indicate the measured PCS response, and the triangles show the TAC response to each set of exposure conditions. It is interesting to note that, in general, each pair of points indicate similar results for each set of exposure conditions.

Table 5 provides a summary tabulation of the Phase-1 dosimetry results. The mean dose and the associated standard deviation for each exposure condition are presented.

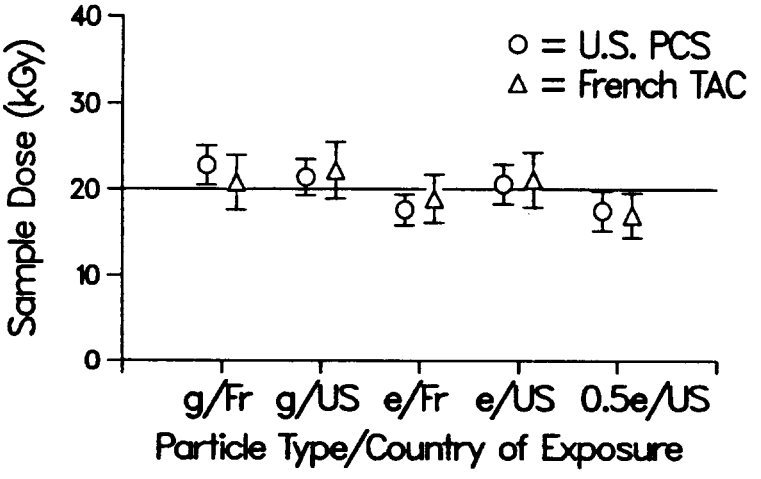

Figure 13: Comparison of SNL and LABRA Dosimetry Results.

TABLE 5

Summary of Phase-1 Dosimetry Results

Irradiation Facility	Particle		Measured Dose (kGy)	
	Type	Energy (MeV)	TAC	PCS
POSEIDON	γ	1.25	20.8 $\pm$ 3.2	22.8 $\pm$ 2.3
NGIF	γ	1.25	22.2 $\pm$ 3.3	21.4 $\pm$ 2.1
VULCAIN	e	1.00	18.9 $\pm$ 2.8	17.6 $\pm$ 1.8
PELLETRON	e	1.00	21.1 $\pm$ 3.2	20.6 $\pm$ 2.3
PELLETRON	e	0.50	17.0 $\pm$ 2.6	17.5 $\pm$ 2.3

In conclusion, the Phase 1 dosimetry results indicate excellent correlation between the two countries regarding radiation exposure conditions and dosimetry measurement techniques.

5. SAMPLES

The objective of the second part of the Phase-1 correlation study was to compare the methods used for measuring radiation induced changes in mechanical properties of the polymer samples. After irradiation, during phases 2 and 3 the changes in tensile strength and elongation at break and hardness of polymer materials will be determined. It is therefore necessary to ensure that the calibration of French and American measuring equipment is comparable.

5.1 Equipment Used at LABRA

5.1.1 Traction Machine

Tensile strength and elongation at break are measured on a ZWICK traction machine, model 7025/3 installed in a room with a thermostatically controlled temperature of 21°C.

A mechanical extensometer is placed at the center of each sample, with an initial opening of 1 cm. Traction speed is 50 mm per minute (French Standard NFT 51034).[8]

The accuracy of the tensile strength and elongation measurements at break are equal to 5%, when standardized H2 dumbbells are used for the tests.

5.1.2 Hardness Tester

The shore hardness measurements are performed on a ZWICK hardness tester.

So as to be able to measure the hardness of 1 mm thick sheets, four thicknesses of the same polymer are stacked in the tester (French Standard NFT 51109).[9]

5.2 Equipment Used at SNL

5.2.1 Tensile Test Machine

Tensile strength and elongation at break are measured on an INSTRON, Model 1000, tensile test machine. The device is installed in a laboratory area without any special temperature or humidity controls.

An incremental extensometer is placed at the center of each sample, with an initial clamp separation of 25 mm, and the crosshead speed is set at 500 mm per minute (ASTM D412).[10]

The rated accuracy of the INSTRON 1000 tensile test machine is within 5% under full-load conditions.

5.2.2 Hardness Tester

Hardness measurements were performed on specimens cut from each halfsheet evaluated at SNL.

The U.S. hardness measurements are performed using a Shore A-2 durometer mounted on a constant load operating stand. The stand incorporates the use of a 822 gram dead weight to minimize variations in readings due to variable pressure of manual applications of the durometer.

Hardness measurements followed the methods as recommended in ASTM D2240[11] ("Standard Test Methods for Rubber Property--Durometer Hardness"). The hardness measurements were performed on 1-mm thick and 6-mm wide straight strips cut from the same halfsheets. Five of those specimens were staked on top of one another then the durometer indentor point was brought into contact with the top strip, and the durometer reading was recorded. After testing the top strip at five positions, as shown in Figure 14, it was moved to the bottom of the stack and the specimen then on top was tested in the same manner. This process continued until all five strips of the halfsheet had been tested.

5.2.3 Density Measurements

The sample density measurements performed at SNL[12] are based on a technique commonly referred to as Archimedes' Principle, wherein a body immersed in a static fluid is acted upon by a vertical force that is equal to the weight of the fluid displaced. In essence, a small piece is cut from the end of a tensile strip; the weight of the piece is determined twice--once dry and once immersed completely in water. The difference between the dry weight and the submerged weight reading is equivalent to the weight of water displaced and can be converted to the volume of the piece. The piece's density is then obtained by dividing its dry mass by its measured volume.

This technique is simple and inexpensive, in that the only equipment required is a mass balance and a thermometer. The mass balance used at SNL is a Metler Balance, Type H5, with an accuracy of 0.01%.

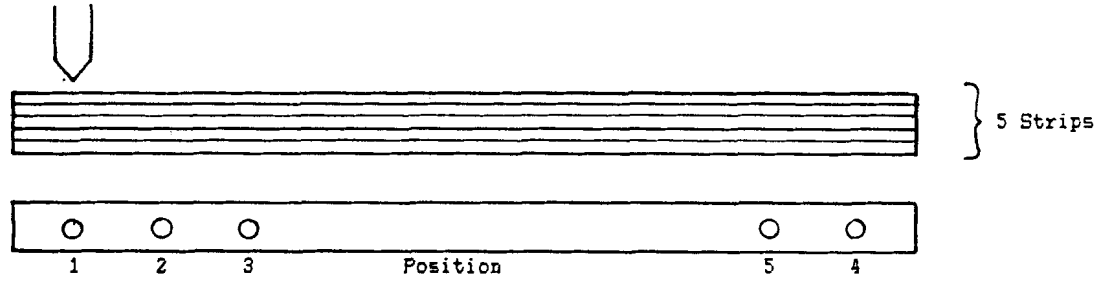

Figure 14: Conditions and Position of Durometer Indentor Point During SNL Hardness Testing.

5.3 Test Specimens

The organic material studied during the Phase-1 tests was ethylene propylene rubber (EPR). Two formulations of EPR were used for normalization: one was a French formulation (Table 6), the other a U.S. formulation (Table 7). Each EPR formulation was made into 150 mm x 150 mm (±2 mm) sheets, 1 mm thick, from which dumbbells and straight strips were cut after exposure for postirradiation measurements. The U.S. used straight strips (150 mm x 6 mm x 1 mm) for postirradiation measurements; the French used H2 dumbbells (see Figure 15).

All irradiations were performed on whole sheets after which each sheet was cut in half, and one-half shipped to the other research facility. Each facility formed the required tensile specimens from its half of the exposed sheet.

Prior to performing the Phase-1 EPR irradiations, Sandia performed tensile tests on six straight strips (described above) and on six dumbbell samples cut using an ASTM standard die.[10] In each case, the samples were cut from unirradiated sheets of the same EPR formulation (Table 7). The purpose of these tests was to quantify any geometrical differences on the Phase-1 tensile test results.

The results of the Sandia tests revealed that 1-mm thick strips exhibited ultimate elongation values 18% below those for the dumbbells, and the average ultimate tensile strength for strips was 2% greater than that for dumbbells. For the case of 2-mm thick specimens, the results indicated that strips had ultimate elongations 4% higher and ultimate tensile strengths 9% lower than those for dumbbell samples. These results are for crosshead speeds of 500 mm/minute and were performed on specimens made up of unirradiated SNL EPR. Since, with the exception of the 1-mm thick strip ultimate elongation, these results were within the ±10% leeway provided for in other aspects of the Phase-1 test series, it was decided that SNL would continue using strips.

5.3.1 French EPR

The French polymer used for the comparison of mechanical properties is an EPR elastomer. This ethylene propylene copolymer is sold by the Le Joint Francaise Company under the code number 10,598. The formula provided by the manufacturer is given in Table 6.

This material was made in the form of sheets, 150 x 150 mm and 1 mm thick.

TABLE 6

French EPR Formulation

EPR No. 10598

Supplier - "Le Joint Francaise"

Ingredient	Parts
Vistalon EPR 404	100
Carbon Black SRS-N 762	55.0
Permanax T.Q.	0.25
Altufane DECZ	0.25
Zinc Oxide	3.0
Sulfur	0.4
Perkadox S.E.B.	4.0
Total	162.9

TABLE 7

U.S. EPR Formulation

EPR No. 1482

Ingredient	Parts
Nordel 2722	90
Low Density Polyethylene	20
Zinc Oxide	5
Parafin Wax	5
Litharge	5
Zinc Salt	2
Aminox	1
Treated Calcined Clay	60
Vinyl Silane	1
SRF Black	2
Di-Cup 40	4
Total	195

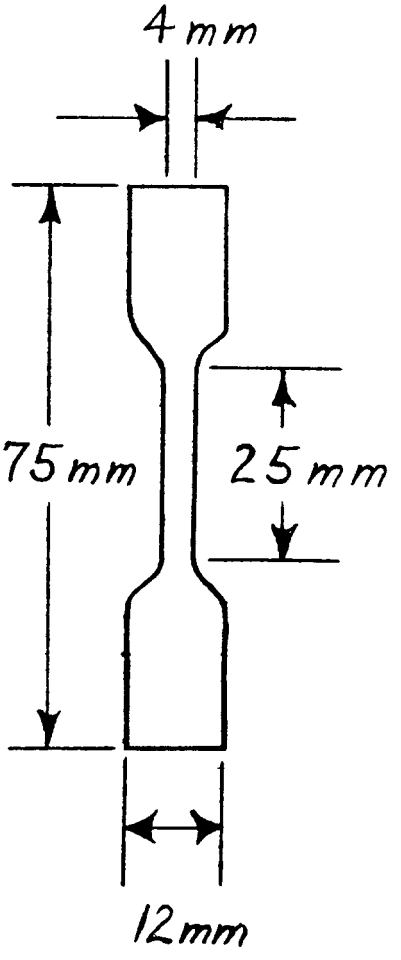

Figure 15: H2 Dumbbell Tensile Specimen.

LABRA supplied a total of six EPR sheets for the Phase-1 test series. The number and disposition of these EPR sheets were as follows:

2-unirradiated control (1 sent to Sandia for measurement),
1-irradiated at VULCAIN (1/2 sent to Sandia for measurement),
1-irradiated at POSEIDON (1/2 sent to Sandia for measurement),
1-sent to Sandia for irradiation at PELLETRON (1/2 returned to LABRA for measurement), and
1-sent to Sandia for irradiation at Sandia's GIF (1/2 returned to LABRA for measurement).

After or before irradiation, the sheets were divided into two parts, one part was tested by LABRA in France and the other by SNL in the United States.

From the part of the polymer material analyzed in France, LABRA cut 12 H2 standard halters that were gripped by the traction machine. The hardness tests were made at the ends of the halters.

5.3.2 U.S. EPR

The American polymer used for the comparison of mechanical properties is an EPR elastomer. This ethylene propylene copolymer was fabricated at SNL and is identified as 1482. The U.S. EPR formulation is given in Table 7.

This material was made in the form of 150 x 150 mm sheets, 1 mm thick.

SNL supplied a total of five EPR sheets for the Phase-1 test series. The number and disposition of the EPR sheets were as follows:

1-unirradiated control (1/2 sent to LABRA for measurement),
1-irradiated at PELLETRON (1/2 sent to LABRA for measurement),
1-irradiated at Sandia GIF (1/2 sent to LABRA for measurement),
1-sent to LABRA for irradiation at VULCAIN (1/2 returned to Sandia for measurement), and
1-sent to LABRA for irradiation at POSEIDON (1/2 returned to Sandia for measurement).

The sheets were divided into two halves, one half was tested by LABRA in France and the other by SNL in the United States. The French cut the EPR sheets in half prior to irradiation, and the U.S. cut the EPR sheets after irradiation. Of those sheets (French and American) irradiated and cut in half in the U.S., the sheets were cut from top-to-bottom and the left-half (as viewed from the irradiation source) was sent to LABRA for testing. The right-half of each sheet was tested at SNL.

From the part of the polymer material analyzed in the U.S., SNL cut 10-12 tensile strips (150 mm long by 6 mm wide). The hardness tests were made at the ends of these strips (see Figure 14), and density specimens were cut from one end of three strips.

5.4 Irradiation

5.4.1 γ irradiation

A sheet of French polymer and a sheet of American polymer were irradiated in the POSEIDON irradiator under conditions exactly identical for those set for irradiation of the dosimeters.

Dose rate: 2.8 Grays per second
Total dose: 150,000 Grays.

All exposures were performed in air under the prevailing ambient conditions of temperature, pressure, and humidity. Figure 1 shows the configuration of the sample and the cobalt-60 source during the photon exposures.

Sandia performed the Phase-1 gamma exposures at the NGIF. Each sample was exposed to Cobalt-60 gammas at a dose rate of 2.8 ± 0.28 $Gy \cdot s^{-1}$ and to a total front surface dose of 150 ± 15 kGy. All exposures were performed in air under the prevailing ambient conditions of temperature, pressure, and humidity. Additionally, gamma radiation was incident on only one face of the EPR sheets. Figure 4 shows the configuration of the sample and the Cobalt-60 source during the photon exposures.

5.4.2 Irradiation Via Accelerated Electrons

A sheet of French polymer and a sheet of American polymer are first cut into two parts, and each of the four half-sheets was placed in the middle of the polystyrene support. The support plate was then placed under the VULCAIN electron accelerator in exactly the same position as during the irradiation of the dosimeters.

The VULCAIN electron accelerator was adjusted to the same conditions as those set for the irradiation of the dosimeters; only the irradiation period was changed to 15 hours.

Each EPR sample was exposed to 1.0 MeV electrons at an average dose rate of 2.8 $\pm$ 0.28 $Gy \cdot s^{-1}$ to a total front surface dose of 150 $\pm$ 15 kGy. All exposures were performed in air under the prevailing ambient conditions of temperature, pressure, and humidity. Additionally, electron radiation was incident on only one face of the EPR sheets.

Sandia performed all electron exposures at the PELLETRON facility. Each EPR sample was exposed to 1.0 MeV electrons at an average dose rate of 2.8 $\pm$ 0.28 $Gy \cdot s^{-1}$ to a total front surface dose of 150 kGY $\pm$ 15 kGy. All exposures were performed in air under the prevailing ambient conditions of temperature, pressure, and humidity. Additionally, electron radiation was incident on only one face of the EPR sheets. Figure 10 shows the relationship of the sample to the electron accelerator window during the exposures.

5.5 Measurement Results

Tables 8, 9, and 10 show the results of the tensile strength, elongation, and hardness measurements made at LABRA and SNL on the French and American samples. Each result is the ratio of the irradiated sample property to the unirradiated sample property (i.e., TS/TS_0, e/e_0, and H/H_0). The uncertainty of each sample set is also provided in the tables.

Each measurement made at LABRA is the average of 12 tensile tests. When a test measurement differed abnormally from the mean, it was withdrawn and a new average calculated. The number of samples kept for determining the averages varied from 5 to 12.

Each tensile measurement made at SNL is the average of 10-12 tensile tests. Some individual tensile measurements were immediately rejected due to anomalies occurring during the test. Such anomalies include slippage of the specimen in the tensile machine jaws or the specimen breaking where it was clamped in the jaws. A total of seven measurements was rejected because of anomalous occurrences. Additionally, when a test measurement differed abnormally from the mean by more than twice the standard deviation of the sample set, it was withdrawn and a new average calculated. This method follows Chauvenet's criterion for rejecting abnormal values once from a data set.[13] A total of ten specimen results was rejected using this method. The number of samples kept for determining the new averages varied from 7 to 11.

TABLE 8

Comparison of normalized EPR tensile strength results obtained by LABRA and SNL. Exposure dose was 150 kGy. (Values given are the normalized mean and associated uncertainty.)

Particle Type	Facility	Specimen	French Measurement	U.S. Measurement
e	VULCAIN	French	1.00 ± 0.11	0.94 ± 0.08
		U.S.	1.07 ± 0.11	1.06 ± 0.04
	PELLETRON	French	0.88 ± 0.07	0.87 ± 0.08
		U.S.	1.00 ± 0.09	1.13 ± 0.05
γ	POSEIDON	French	0.92 ± 0.07	0.80 ± 0.09
		U.S.	1.04 ± 0.09	1.09 ± 0.04
	NGIF	French	0.90 ± 0.08	1.06 ± 0.09
		U.S.	0.98 ± 0.11	1.11 ± 0.05

TABLE 9

Comparison of normalized EPR elongation results obtained by LABRA and SNL. Exposure dose was 150 kGy. (Values given are the normalized mean and associated uncertainty.)

Particle Type	Facility	Specimen	French Measurement	U.S. Measurement
e	VULCAIN	French	0.93 ± 0.08	0.85 ± 0.07
		U.S.	0.70 ± 0.08	0.68 ± 0.05
	PELLETRON	French	0.81 ± 0.06	0.80 ± 0.07
		U.S.	0.68 ± 0.08	0.69 ± 0.06
γ	POSEIDON	French	0.87 ± 0.04	0.77 ± 0.08
		U.S.	0.80 ± 0.09	0.85 ± 0.04
	NGIF	French	0.84 ± 0.08	0.93 ± 0.07
		U.S.	0.84 ± 0.10	0.82 ± 0.05

TABLE 10

Comparison of normalized EPR Hardness (Shore A) results obtained by LABRA and SNL. Exposure dose was 150 kGy. (Values given are the normalized mean and associated uncertainty.)

Particle Type	Facility	Specimen	French Measurement	U.S. Measurement
e	VULCAIN	French	1.02 ± 0.05	1.02 ± 0.04
		U.S.	1.01 ± 0.03	0.77 ± 0.04
	PELLETRON	French	1.03 ± 0.04	1.01 ± 0.04
		U.S.	1.02 ± 0.04	0.94 ± 0.08
γ	POSEIDON	French	1.02 ± 0.04	1.04 ± 0.05
		U.S.	1.02 ± 0.03	1.01 ± 0.02
	NGIF	French	1.03 ± 0.04	1.03 ± 0.05
		U.S.	1.00 ± 0.03	0.97 ± 0.08

Tables 8 and 9 show that in spite of significantly different traction speed for the samples, measurement of the tensile strength ratio of the irradiated and nonirradiated samples is very similar whether measured at LABRA or SNL.

The same is observed for the elongation at break; the French and American measurements closely approximate each other.

Irradiation to 150 kGy of an EPR sample caused only slight degradation. The material hardens slightly; its elongation at break decreases from 1 to 0.85 for the French material and from 1 to 0.7 for the American material when irradiated under an electron beam. The variation in hardness is difficult to determine in measuring the shore A hardness. The variations recorded using this method are around 1%.

5.5.1 U.S. Results--French and American EPR Formulations

Figure 16 compares all of the postirradiation test results of both countries. The points are plotted in pairs,

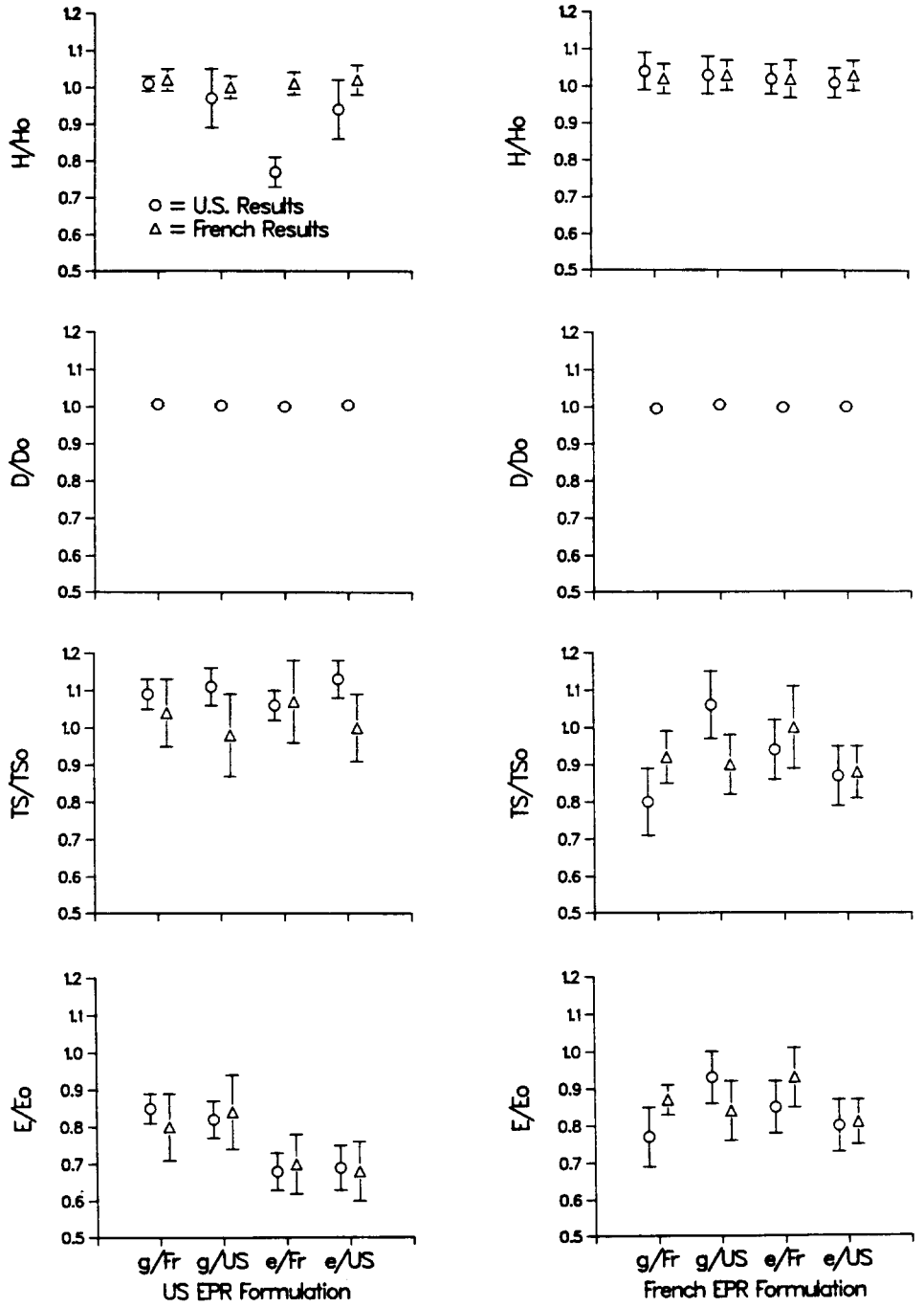

Figure 16: Comparison of LABRA and SNL Postirradiation EPR Test Results. The plotted points represent the normalized average values of hardness (H/H_O), density (D/D_O), ultimate tensile strength (TS/TS_O), and elongation E/E_O) obtained from postirradiation measurements. The error bars represent the associated uncertainties.

representing similar exposure locations (U.S. or France) and radiation particle type (gamma or electron).

As can be seen, hardness of irradiated samples shows little change from the hardness of unirradiated sheets for both EPR formulations. The single case of the low hardness exhibited by the U.S. EPR sheet exposed to electrons in France is postulated to be due to some anomaly occurring during the fabrication process. Density measurements revealed that there appeared to be no density changes in either EPR formulation, even after exposure to 150 kGy front surface dose.

Ultimate tensile strength results, however, did show differences between the two material formulations. In the case of the U.S. EPR formulation, exposed material ultimate tensile strength increased to values between 5% and 13% above that for the unirradiated samples. But, in the case of the French EPR formulations, the exposed material tensile strengths decreased to as low as 20% below that for the unirradiated samples--although the sheet exposed to gammas in the U.S. exhibited an average tensile strength 5% greater than the unirradiated sheet value.

Ultimate elongation results again revealed some surprises. First, the elongations of irradiated U.S. EPR sheets decreased, as expected, but in addition, showed some correlation between irradiation particle type--that is, the sheets irradiated by electrons showed an additional 15% decrease in elongation at break over that exhibited by sheets irradiated by photons. Whether this phenomenon is real and repeatable remains open to question and should, hopefully, be resolved during the Phase-2 Screening Tests. The ultimate elongation results for the French EPR formulation did not exhibit any noticeable correlation between irradiation particle type, nor did they indicate any consistency in the amount of elongation reduction due to exposure to 150 kGy at the front surface. The pattern, in fact, tends to follow the ultimate tensile strength test results very closely.

5.5.2 French Results--French and American EPR Formulations

As was the case for the U.S. results, the French results indicate that hardness of irradiated samples shows little change from that of the unirradiated sheets. Note that the French recorded a hardness value for the U.S. EPR sheet exposed to electrons in France, which was consistent with the hardness values recorded for the other EPR sheets. The tensile data recorded by the French agrees reasonably well

with the values provided by SNL. Again, it is interesting to note the same pattern for the elongation data of U.S. EPR as was found by SNL, whereas no similar pattern exists for the French EPR.

In conclusion, the data reveals that the U. S. and French postirradiation measurement results for EPR are comparable.

6. DISCUSSION

In general, the Phase-1 results indicate that consistency is achievable between the two countries for the conditions of material exposure and postirradiation testing employed. This is supported, in part, by the fact that the error bars of the two data sets do overlap, and the very similar elongation results for the U.S. EPR may indicate a close correlation between the two countries' results.

An agreement was reached to continue with the program's Phase-2 Screening Test effort, during an information exchange meeting held at Saclay, France on October 1, 1985. Since many of the material exposure conditions and tests conducted during Phase-1 will be repeated as part of the screening test series, it is expected that many of the questions concerning some of the Phase-1 test results will be answered then.

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As part of the ongoing multi-year joint NRC/CEA international cooperative test program to investigate the dose-damage equivalence of gamma and beta radiation on polymer base materials, dosimetry and ethylene-propylene rubber (EPR) specimens were exchanged, irradiated, and evaluated for property changes at research facilities in the U.S. (Sandia National Laboratories) and France (Compagnie ORIS Industrie). The purpose of this Phase-1 test series was to normalize and cross-correlate the results obtained by one research center to the other, in terms of exposure (1.0 MeV accelerated electrons and Co^{60} gammas) and postirradiation testing (ultimate elongation and tensile strength, hardness, and density) techniques. The dosimetry and material specimen results indicate good agreement between the two countries regarding the exposure conditions and postirradiation evaluation techniques employed.

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